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(54) TELEMETRY OF DIAGNOSTIC MESSAGES FROM A MOBILE ASSET TO A REMOTE STATION

TELEMETRIE VON DIAGNOSENACHRICHTEN VON EINEM MOBILEN GEGENSTAND ZU EINER ENTFERNTEN STATION

TÉLÉMETRIE DE MESSAGES DE DIAGNOSTIC PROVENANT D'UNE ENTITÉ MOBILE ET À DESTINATION D'UNE STATION À DISTANCE

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(56) References cited:
EP-A- 0 292 811 **EP-A1- 0 748 082**
FR-A- 2 693 068 **US-A- 5 065 321**
US-A- 5 742 336 **US-A- 5 867 801**

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Description

[0001] This invention relates generally to remote monitoring and diagnostics, and more specifically relates to telemetry of diagnostic messages from a mobile asset to a remote service center. One embodiment of the present invention is a telemetry system employing airborne sensors and telemeters to transmit maintenance data (such as performance data of an aircraft engine) from an aircraft-in-flight to a ground based service center.

[0002] Remote monitoring and diagnosing of the condition, performance, and failure of parts, equipment and systems carried by mobile assets such as airplanes, turbines, locomotives and medical systems is becoming increasingly important as industry struggles to improve safety, reduce maintenance costs and deliver efficient, timely and cost effective maintenance services to its customers. For that reason, remote maintenance services are seen by today's service oriented businesses as an important growth area. Remote monitoring and diagnosing capability is quickly becoming a key element in providing high-technology, value-added services for an installed equipment base which equipment base may include mobile assets such as power generation equipment, aircraft engines, medical imaging systems, and locomotives.

[0003] By monitoring the performance of such equipment and systems, an indication that a system is malfunctioning can be obtained. By providing diagnostic messages which contain information about a malfunctioning system, a measure of safety is obtained that can be of particular importance in ensuring the system is capable of performing as required. In addition, such information can be utilized to initiate a maintenance cycle before placing the system into a subsequent cycle of operation.

[0004] Telemetry systems for monitoring mobile assets such as road vehicles, airborne missiles, and railroad engines, are described in EP-A-0,292,811, FR-A-2,693,068, and US-A-5,065,321. US-A-5,867,801 describes a vehicle tracking and monitoring system for monitoring railway cars within a defined radius of a receiver for wireless communication. US-A-5,742,336 describes an aircraft surveillance and recording system including a satellite relay. EP-A-0,748,082 describes a network of tracked mobile assets which are temporarily located in an area such as a railway yard. Control systems for devices such as turbines used for generation of electricity or turbines used in aircraft engines typically monitor a variety of turbine performance parameters, including speed, temperatures, and stresses on the turbine assembly. Prior art systems provide for monitoring these parameters in flight. However, many of the problems associated with relaying these parameters to a ground service center while the aircraft is in flight remain to be solved.

[0005] A significant problem encountered in the art of wireless digital communications of performance parameters relates to the frequency and, more importantly, the power at which telemetry devices can transmit RF signals. Until the enactment by the Federal Communications Commission (FCC) of Part 15.247 of the FCC Rules and Regulations, aircraft telemetry systems were primarily limited to the VHF band (174-216 MHz), and could only operate at very low transmission powers of less than 0.1 milliwatts (mW). (See FCC Part 15.241.) This restriction on the transmission power has significantly limited the transmission range (i.e., the maximum distance between the transmitter and the receiver) of airborne telemetry devices. Restrictions also place limits on the data rate or "bandwidth" at which the telemetry devices can transmit data.

[0006] Because of these factors the frequency bands available for transmission of information from an aircraft to ground, and vice versa, is limited. Further, there are increasing demands for other types of communications, such as voice, to utilize these available regulated bands. Adding diagnostic information channels often requires modifications to the airframe of the aircraft to add additional antennas. Because of the cost of these structural modifications, and the high recurring cost of acquiring transmission time for relaying flight performance data in the regulated frequency bands, there is a pressing need for improved systems and methods for transmitting aircraft diagnostic information from an aircraft to a ground station.

[0007] The invention is defined by the telemetry system of independent claim 1.

[0008] Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 is a pictorial block diagram of a telemetry system according to one embodiment of the present invention.

FIG 2 is a block diagram of a telemeter according to one embodiment of the present invention.

FIG. 3 illustrates an example of a circle of coverage to an aircraft at an altitude of 20,000ft.

FIG. 4 is a pictorial diagram showing a plurality of remote stations configured in accordance with one embodiment of the present invention.

FIG. 5 shows exemplary specifications for a mobile asset to remote station link according to one embodiment of the present invention.

FIG. 6 shows exemplary specifications for a ground station to mobile asset link according to one embodiment of the present invention.

FIG. 7 shows an example diagnostic message format according to one embodiment of the invention.

[0009] A telemetry system 10 is illustrated in FIG. 1. Telemetry system 10 comprises a telemeter 100, a transmitter 118 and a remote station 200. Telemeter 100 is carried upon a mobile asset, such as an aircraft 20, locomotive 22 , ship 24, or the like and configured to monitor the condition of the asset upon which it is installed. Telemeter 100 in conjunction with transmitter 118 transmits messages, referred to herein as diagnostic messages, containing information about the condition and performance of the assets to remote station 200. The term "condition" refers to the state of readiness, or fitness for operation of an asset or of a particular component of an asset.

[0010] Diagnostic messages are relayed directly from the asset, such as aircraft 20, being monitored (referred to herein as a source) to a remote station 200 (referred to herein as a destination). Diagnostic messages may also be relayed in series from a source asset, such as aircraft 20, to a successor asset, such as aircraft 21, and in some cases from a successor asset to another successor asset, and so on until the diagnostic message arrives at its remote station destination 200.

[0011] An exemplary format suitable for diagnostic messages is illustrated in FIG. 7. The message format comprises a synchronization preamble, address bits, priority bits if desired, a data field, an encryption flag denoting the presence or absence of encryption of the data in the data field, and an error detection field.

[0012] Diagnostic messages are relayed between source assets, successor assets and remote station destinations via down links 45. Down links 45 according to the present invention are communications channels comprising unlicensed, or Industrial/Scientific/Medical (ISM) band, transmissions. Three ISM bands are now available in the United States for using spread-spectrum communications techniques: 902-928 MHz; 2400-2483.5 MHz; and 5725-5850 MHz.

[0013] Accordingly, transmitter 110, according to one embodiment of the invention, is adapted to transmit in an ISM frequency band. In one embodiment of the present invention data links 45 further include non ISM band radio frequency channels such as those licensed by the Federal Communications Commission (FCC).

[0014] In one embodiment of the present invention telemeter 100 is installed upon aircraft 20. Telemeter 100 monitors one or more jet engine conditions of aircraft 20 and transmits messages containing information about the performance of the aircraft between aircraft 20 and remote station 200. Remote station 200 utilizes the information contained in the messages to assess engine performance, identify and predict failure conditions, and in one example to relay corrective signals to aircraft 20 via data uplink 30 to correct or compensate for failure conditions. In one example, data uplink 30 comprises ISM band transmissions. In another example data uplink 30 comprises commands and data in an FCC licensed radio frequency band.

[0015] A telemeter 100 according to an example is illustrated in block diagram form in FIG. 2. Telemeter 100 comprises as major components transmitter 118, receiver 116, diagnostic message processor 150, memory 152, display 190, condition sensors 320 and a first auxiliary processor 141. Condition sensors 320 monitor performance conditions and parameters such as turbine speed, and exhaust gas temperature.

[0016] In one example, telemeter 100 is implemented using avionics equipment already in place on aircraft 20, as for example VHF, or UHF transceivers for other avionics applications licensed by the FCC for operation in RF bands. For example, Very High Frequency (VHF) transceiver units, not used over oceans where there is no line of sight to a ground station, may be employed to transmit and receive diagnostic messages on licensed bands during periods when these VHF transceivers are inactive. In one example, transmitter 118 includes an ISM modem of a type readily commercially available.

[0017] In one example, telemeter 100 includes a low power 2.4 GHZ ISM transceiver, represented in FIG. 2 by receiver 116 and transmitter 118. Receiver 116 and transmitter 118 include modems employing typical direct sequence spread spectrum modulation schemes to modulate a carrier with diagnostic message information. Such schemes may be implemented in synchronous mode or in transmitted reference mode to alleviate the synchronization overhead.

[0018] The ISM band relies on in-flight use of the 2.4 GHz ISM at 2.4GHz -2.4835 GHz. Commercially available chip sets such as the Harris PRISM™ chip set and a wide variety of support electronics are readily commercially available for use in this example. For example, employing Direct Sequence Spread Spectrum (DSSS) techniques to maintain a spreading factor of at least 10, as required by United States FCC regulations. The Harris PRISM set spreads with a factor of 11 and is programmable for up to a factor of 16, making it advantageous.

[0019] An alternative example employs 5.7GHz band transceivers.

[0020] A problem with the use of commercially available ISM chip sets sometimes arises in situations in which the Doppler shifts associated with the relative motion of an aircraft and the ground exceed the performance capabilities of the chip set. Therefore, an example is configured to carry out a method by which the same message is transmitted a plurality of times, the number of retransmission times based on the expected channel losses associated with the communications channel in use. This technique provides increased reliability of the link as data rates decrease.

[0021] The method comprises the following steps. First diagnostic message processor 150 provides a message to be transmitted comprising N information bits to first auxiliary processor 141. Processor 141 is configured to encode the N information bits into B (B greater than N) message bits by means of a forward error correction code, for example, a Hamming code. Next, the B bit message is broken into portions of n-bits each. In one example any fractional piece is padded with trailing zeros or other conventional fillers. The greater the value of n, the more efficient is the random parity coding implementation. However, greater values of n add to the complexity of the decoder. In one example n is chosen to be 12.

[0022] Next, auxiliary processor 141 estimates an expected bit error rate, p. Bit error rate p is the error rate that a ground based receiver will experience on bit by bit demodulation of an ISM transmission at the ISM modem design rate. In one example, p is predetermined and provided to auxiliary processor 141. Based on p, auxiliary processor 141 calculates the channel capacity, C(p) of a Binary Symmetric Channel (BSC) from transmitter 118 to a ground based receiver according to the formula:

$$C(p) = 1 + p\log_2 p + (1 - p)\log_2(1 - p)$$

[0023] Next a system parameter, α, is provided to processor 141 by an operator. System parameter α is chosen to provide sufficient redundancy such that the N information bits are decoded with a desired error rate. Auxiliary processor 141 then sends each of the n-bit portions as m bit code words (m>n). The relationship between m and n is given by:

$$M = f_{ceil}(\alpha\ (n/C(p)))$$

Wherein f_{ceil} is the ceiling function which is the smallest integer larger than or equal to its argument.

[0024] Table 1 shows exemplary link specifications developed by simulating an asset-to-asset link according to one example.

[0025] According to the example shown in Table 1, an airplane to airplane link in the 2.4 GHz ISM band between two aircraft, each at a minimum cruise altitude of 20,000 feet and separated by a line of sight distance of about 400 miles will support about a 1.2kilobit per second link between the two aircraft, without coding, at a bit error rate of no greater than 10^{-5}. In an alternative example the link is operated at a variable data rate depending on the available link margin. In that case, both ends of the link are configured to observe the received error rates, calculated over groups of known bits or by observing various check sum failure rates, and increase or decrease their signaling rates accordingly.

TABLE 1.

Parameter	Value	Remarks
Transmit Power (dBm)	36	
Carrier Frequency (GHz)	2,442	
Wavelength (meter)	0.12285	
Transmit Antenna Gain (dBi)	-2	
Transmitted EIRP (dBm)	34	FCC allows up to 36 dBm
Range (miles)	400	
Range (Km)	643.6	
Free Space Loss (dB)	-156.369	
Boltzmann's Constant	-228.6	
Other Link Losses (dB)	-1	
Receive Antenna Element Gain (dBi)	-2	
Receiver Noise Figure (dB)	3	
Receiver Noise Figure (dimensionless)	1.995262	
Receiver Noise Temperature (K)	288.6261	
Antenna Noise Temperature (K)	70	
System Noise Temperature (K)	358.6261	
System Noise Temperature (dB.K)	25.54642	
Receiver G/T (dB/K)	-27.5464	
Pr/No (dB.bps)	47.68458	
Data Rate (kbps)	1.2	
Data Rate (db-kbps)	0.791812	

(continued)

Parameter	Value	Remarks
Implementation Loss (dB)	-2	
Available Eb/No (dB)	14.89277	
Bit Error Rate	10^(-5)	
Modulation Scheme	DQPSK	
Required Eb/No (dB)	12	
Coding Gain (dB)	0	NO CODING
Margin (dB)	2.89277	

[0026] FIG. 5 shows exemplary link specifications for an asset to remote station link wherein the remote station is a ground based station.

[0027] FIG. 6 shows exemplary link specifications for a remote station to asset link wherein the remote station is a ground station and the asset is an aircraft.

[0028] Telemeter 100 also includes read/write memory 152. Read/write memory 152, which is dynamic random access memory in one example, performs storage of incoming messages for retransmission and keeps a history of system performance measures. System performance measures include, but are not limited to, measures selected from the group comprising: number and size of messages successfully received, number of messages successfully transmitted, latency time distribution, i.e., a histogram of the times that the successfully received messages were stored by the receiving aircraft before they were successfully retransmitted, link quality indicators such as signal to noise estimates, and communications protocol efficiency, e.g. number of transmission retries per message.

[0029] A system 100 for telemetry of information from aircraft in flight to a ground station according to one example typically comprises a plurality of mobile assets, referred to hereinafter as nodes, in radio communication with each other. Each node may be selected from the group comprising aircraft, land vehicles such as a railroad locomotives, ships, ground transmitting or receiving stations, or communications satellites. Each node is equipped with a telemeter 100 for relaying diagnostic messages between nodes and from a source node to a destination ground station. The source node originates the diagnostic message and determines the most efficient link to the desired destination ground station through intermediate nodes. The source node then transmits the diagnostic message to the first node in the link, that node receives and retransmits the diagnostic message to the next mode in the link, etc. until the message is finally received by the desired ground station. In this manner the aircraft pass the data by relay between aircraft in mutual line of sight such that the data is efficiently migrated from the source node to the ground station. According to one example, remote station 250 employs a phased array antenna that has a line of sight to aircraft at cruise altitude.

[0030] In order to establish an efficient link, the source node, and each successive node in the link, must select its successor node such that the message is transmitted from node to node while the successor node is in line of site with the predecessor node. In one example, each node's transceiver is provided with flight plan information in order to facilitate the selection of a successor node to which to transmit the diagnostic message. Flight plan information is information related to the altitudes, flight paths, and times for flights of specific aircraft. In example flight plan information is obtained from an aircraft tracking services. An example of such a system includes, but is not limited to, AirTrack. Airtrack is a real-time aircraft tracking program available from METSYS Software and Services, Cropton, Pickering, North Yorkshire, Y018 8HL, England. Flight plan data from the database is loaded into the Diagnostic message processor 150 of each aircraft's telemeter 100. Thereafter, processor 100 of the source node selects successors based on the flight plan data and desired destination remote station.

[0031] As shown in FIG. 1, remote station 200 comprises a receiver 250 adapted to receive frequencies in an unlicensed frequency band such as an ISM frequency band. One example employs a receiving network 500 comprising several spaced apart remote stations 200 as illustrated in FIG.4. Remote stations 200 are spaced from each other so as to provide receiver coverage over the entire geographical area of interest 120, in this case the United States, as illustrated in FIG. 4.

[0032] The radio horizon for a line of sight path from an object at H feet above the earth is $\sqrt{2H}$ miles. Thus, a radio receiver on the ground near Evendale, Ohio is capable of line of sight contact with a plane at 20,000 feet whose ground point falls in the circle 300 as shown in Figure 3. The circle is about 200 miles in radius. For planes at higher altitudes, the circle of coverage expands. Figure 4 shows a virtual covering of the Continental United States with only 40 receiver sites. A site center is marked with an "x".

[0033] The system includes a protocol for fixing and monitoring schedule and performing monitoring hand-off from receiver site to receiver site. The protocol relies upon a ground-to-air link for flow or transmission control including. Examples of ground to air links suitable for transmission control include, but are not limited to: adaptive transmission rate control; provision/non-provision of error correction coding; power control; and time of transmission.

Claims

1. A telemetry system (10) comprising:

a plurality of telemeters (100), each telemeter (100) carried on board a respective aircraft (20) said telemeters including an input (320) coupled to the output of one or more condition sensors of said respective assets; an output (150) for providing diagnostic messages containing information related to the sensed performance of said respective assets;
each respective asset comprising a respective transmitter (110) having an input coupled to said output of said telemeters for transmitting said diagnostic messages in an ISM frequency band; and
a plurality of remote stations (200) comprising a receiver (116) for receiving said transmitted messages;
a processor (150) for processing said transmitted messages; and
an output (320) for providing information related to the performance of said respective assets to a device adapted to utilize said information;
said remote stations (200) are spaced apart from one another so as to provide receiver coverage over an entire geographical area of interest; and **characterized in that**:
said aircraft (20) comprise nodes in radio communication with each other, and wherein each node has a respective transceiver (110,116) provided with flight plan information to enable it to select a successor node such that said messages are transmitted from node to node while the successor node is in line of sight of a predecessor node.

2. The telemetry system (10) of claim 1, wherein said transmitters (110) transmit electromagnetic energy in the 2400-2483.5 MHz Industrial/Scientific/Medical (ISM) band.

3. The telemetry system (10) according to claim 1 or claim 2, wherein said telemeters (100) further comprise a respective receiver for receiving diagnostic messages in the ISM frequency band.

4. The telemetry system (10) according to claim 1 or claim 3, wherein said transmitters (10) transmit in the 5725-5850 MHz Industrial/Scientific/Medical (ISM) band.

Patentansprüche

1. Telemetriesystem (10), umfassend:

mehrere Telemeter (100), wobei jedes an Bord eines jeweiligen Luftfahrzeugs (20) getragene Telemeter (100) einen Eingang (320) beinhaltet, der mit dem Ausgang eines oder mehrerer Zustandssensoren der jeweiligen Objekte gekoppelt ist;
einen Ausgang (150) zum Bereitstellen von Diagnosemeldungen, die Informationen enthalten, die sich auf die erfasste Leistung der jeweiligen Objekte beziehen;
wobei jedes jeweilige Objekt einen jeweiligen Sender (110) umfasst, der einen Eingang aufweist, der mit dem Ausgang der Telemeter zum Senden der Diagnosemeldungen in einem ISM-Frequenzband gekoppelt ist; und
mehrere entfernte Stationen (200), die einen Empfänger (116) zum Empfangen der gesendeten Meldungen umfassen;
einen Prozessor (150) zum Verarbeiten der gesendeten Meldungen; und
einen Ausgang (320) zum Bereitstellen von Informationen, die sich auf die Leistung der jeweiligen Objekte beziehen, an eine Vorrichtung, die angepasst ist, um die Informationen zu verwenden;
die entfernten Stationen (200) voneinander beabstandet sind, um eine Empfängerabdeckung über ein gesamtes geographisches Gebiet von Interesse bereitzustellen; und
dadurch gekennzeichnet, dass:
das Luftfahrzeug (20) Knoten umfasst, die in Funkverbindung miteinander stehen, und wobei jeder Knoten einen jeweiligen Sendeempfänger (110, 116) aufweist, der mit Flugplaninformationen versehen ist, um es ihm zu ermöglichen, einen Nachfolgeknoten derart auszuwählen, dass die Meldungen von Knoten zu Knoten gesendet werden, während der Nachfolgeknoten sich in Sichtlinie eines Vorgängerknotens befindet.

2. Telemetriesystem (10) nach Anspruch 1, wobei die Sender (110) elektromagnetische Energie in dem 2400-2483,5 MHz Industrial/Scientific/Medical(ISM)-Band senden.

3. Telemetriesystem (10) nach Anspruch 1 oder 2, wobei die Telemeter (100) ferner einen jeweiligen Empfänger zum Empfangen der Diagnosemeldungen in dem ISM-Frequenzband umfassen.

4. Telemetriesystem (10) nach Anspruch 1 oder 3, wobei die Sender (10) in dem 5725-5850 MHz Industrial/Scientific/Medical(ISM)-Band senden.

Revendications

1. Système de télémesure (10) comprenant :

   une pluralité de télémètres (100), chaque télémètre (100) étant transporté à bord d'un aéronef respectif (20), lesdits télémètres comportant une entrée (320) couplée à la sortie d'un ou plusieurs détecteurs d'état desdites ressources respectives ; une sortie (150) pour fournir des messages de diagnostic contenant des informations relatives aux performances détectées desdites ressources respectives ;
   chaque ressource respective comprenant un transmetteur respectif (110) ayant une entrée couplée à ladite sortie desdits télémètres pour transmettre lesdits messages de diagnostic dans une bande de fréquences ISM ; et
   une pluralité de stations distantes (200) comprenant un récepteur (116) pour recevoir lesdits messages transmis ; un processeur (150) pour traiter lesdits messages transmis ; et
   une sortie (320) pour fournir des informations relatives à la performance desdites ressources respectives à un dispositif adapté à utiliser lesdites informations ;
   lesdites stations distantes (200) sont espacées les unes des autres de manière à fournir une couverture de récepteur sur toute une zone géographique d'intérêt ; et **caractérisé en ce que** :
   ledit aéronef (20) comprend des nœuds en communication radio les uns avec les autres, et chaque nœud ayant un émetteur-récepteur (110, 116) respectif muni d'informations de plan de vol pour lui permettre de sélectionner un nœud successeur de telle sorte que lesdits messages sont transmis d'un nœud à l'autre tandis que le nœud successeur est en vue d'un nœud prédécesseur.

2. Système de télémesure (10) selon la revendication 1, dans lequel lesdits émetteurs (110) transmettent de l'énergie électromagnétique dans la bande industrielle / scientifique / médicale (ISM) de 2 400 - 2 483,5 MHz.

3. Système de télémesure (10) selon la revendication 1 ou la revendication 2, dans lequel lesdits télémètres (100) comprennent en outre un récepteur respectif pour recevoir des messages de diagnostic dans la bande de fréquences ISM.

4. Système de télémesure (10) selon la revendication 1 ou la revendication 3, dans lequel lesdits transmetteurs (10) transmettent dans la bande industrielle / scientifique / médicale (ISM) de 5 725 - 5 850 MHz.

FIG. 1

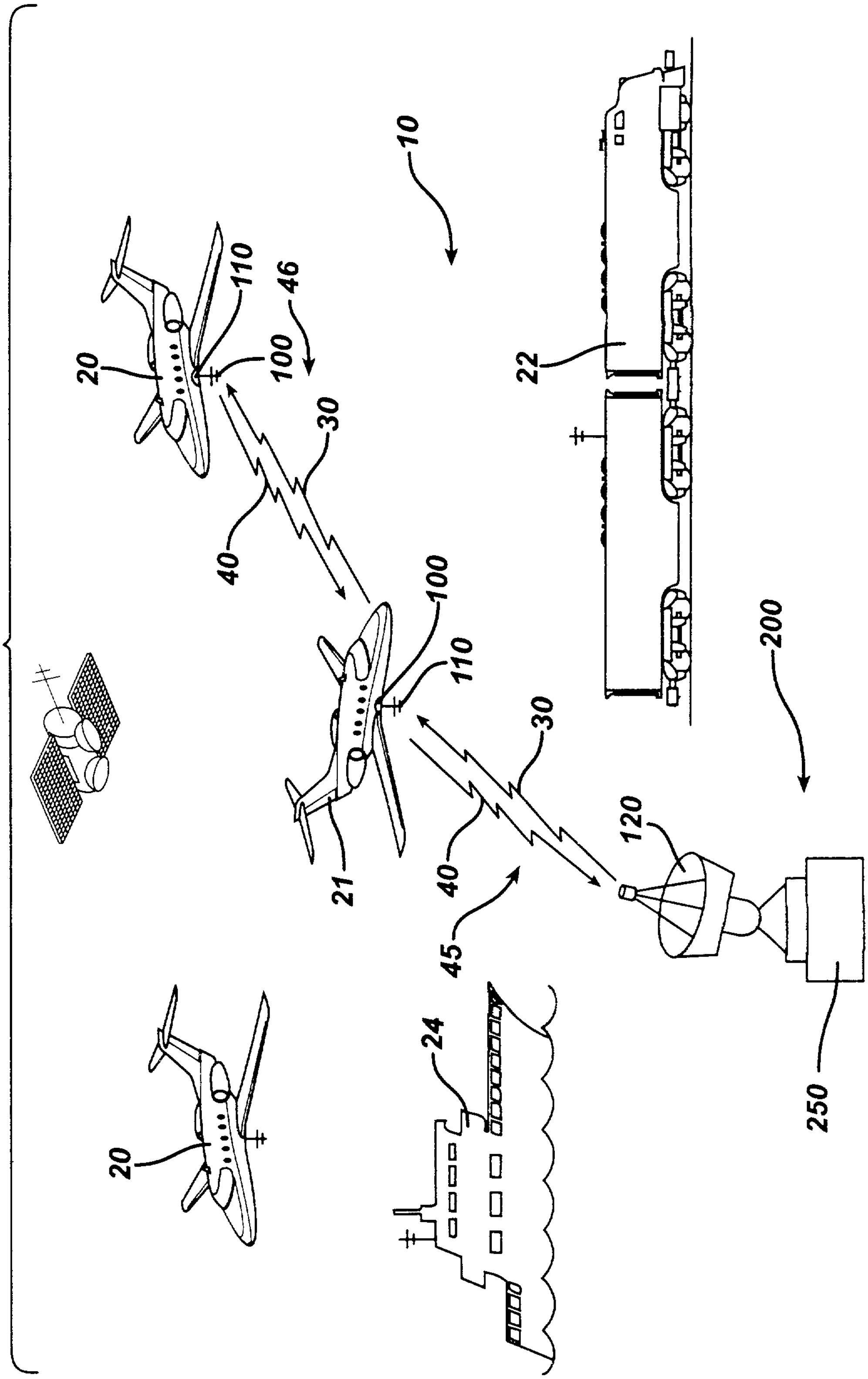


FIG. 2

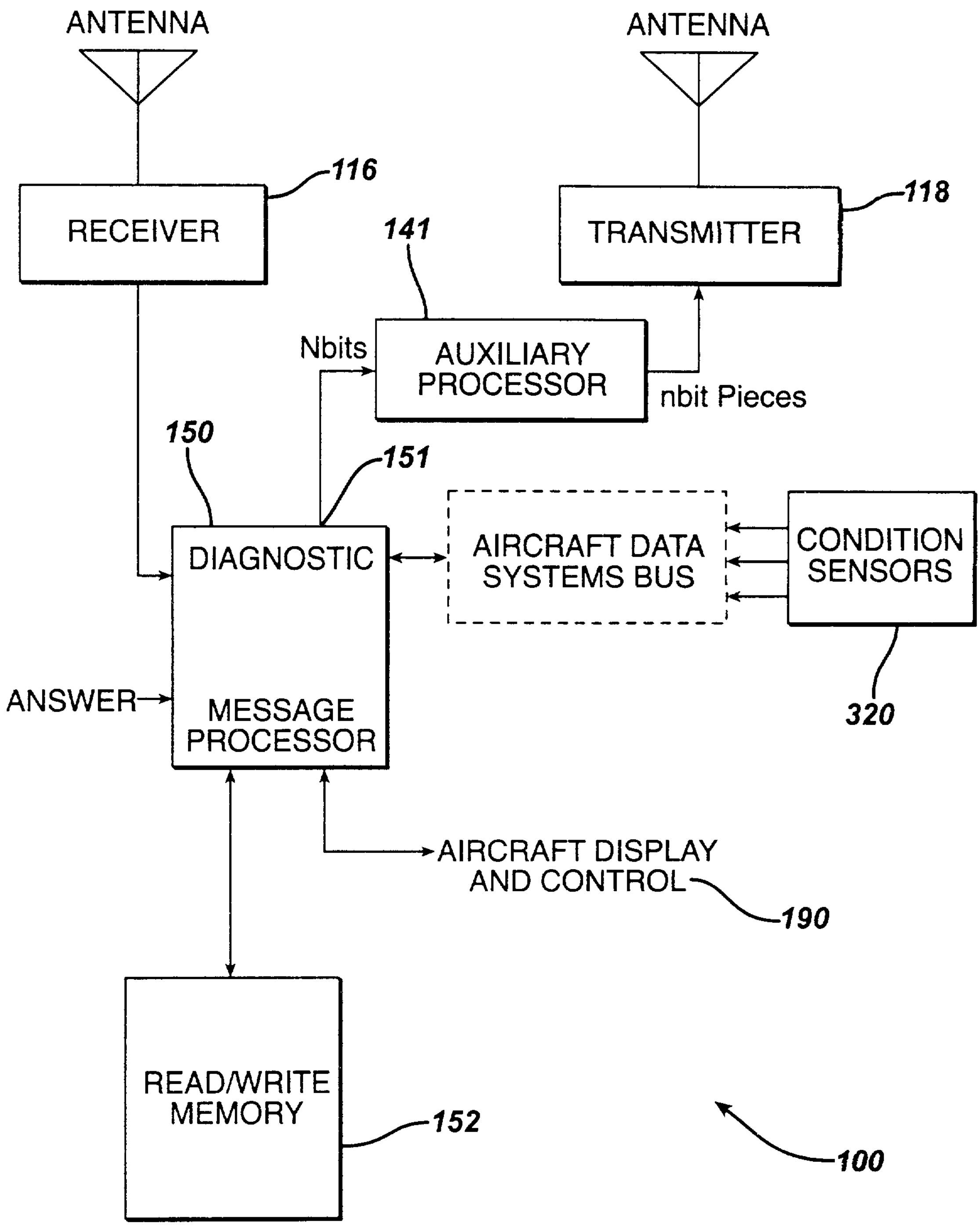
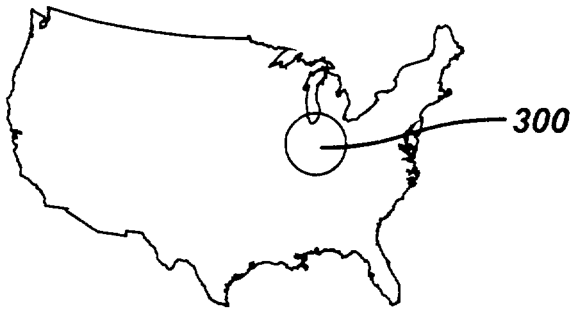
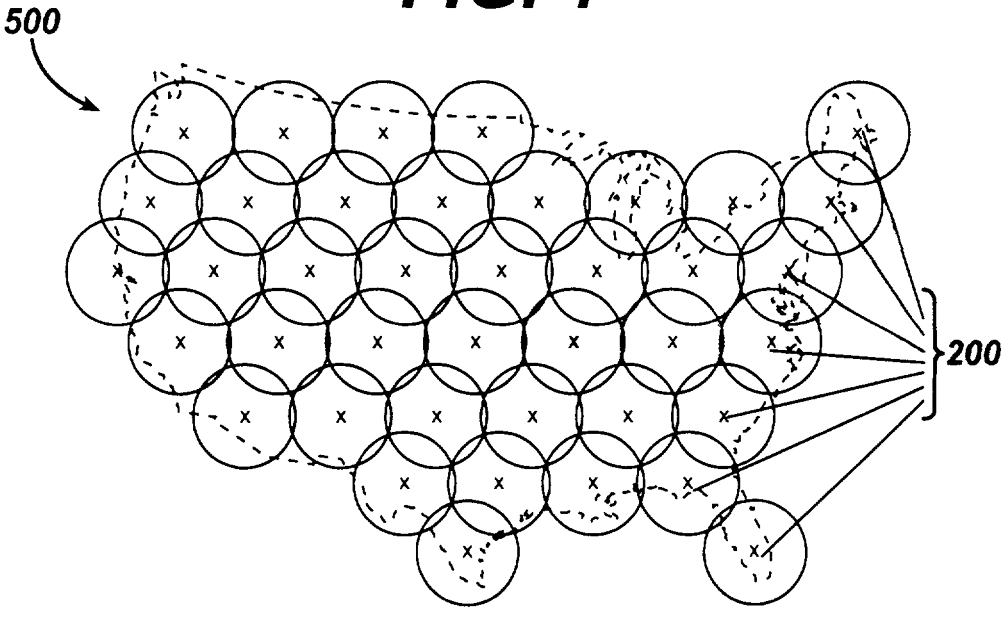

ANTENNA
ANTENNA
116
RECEIVER
141
TRANSMITTER
118
Nbits
AUXILIARY PROCESSOR
nbit Pieces
150
151
DIAGNOSTIC
AIRCRAFT DATA SYSTEMS BUS
CONDITION SENSORS
ANSWER
MESSAGE PROCESSOR
320
AIRCRAFT DISPLAY AND CONTROL
190
READ/WRITE MEMORY
152
100

FIG. 3



Circle of Coverage to Aircraft at 20,000 Feet for a Receiver Located Near Evendale, Ohio

FIG. 4



CONUS Coverage Attained with 40 Receiver Sites

FIG. 5

Parameter	Value	Remarks
Transmit Power (dBm)	35	
Carrier Frequency (GHz)	2.442	
Wavelength (meter)	0.12285	
Transmit Antenna Gain (dBT)	-2	
Transmitted EIRP (dBm)	33	FCC allows up to 36 dBm
Range (Miles)	200	
Range (Km)	321.8	
Free Space Loss (dB)	-150.348	
Boltzmann's Constant	-558.6	
Other Link Losses (dB)	-1	
Receive Antenna Element Diameter (cm)	20	
Receive Antenna Element Efficiency	0.6	60% Efficiency
Receive Antenna Element Gain (dBi)	11.95759	
Number of Receive Array Elements	16	Array Gain of 12 dB
Receive Antenna Array Gain (dBi)	23.99879	
Receiver Nose Figure (dB)	3	
Receiver Noise Figure (dimensionsless)	1.995262	
Receiver Noise Temperature (K)	288.6261	
Antenna Noise Temperature (K)	100	Tsky=70 Tgnd=30
System Noise Temperature (K)	388.6261	
System Noise Temperature (dB.K)	25.89532	
Receiver G/T (dB/K)	-1.89653	
Pr/No (dB.bps)	78.35507	
Data Rate (kbps)	1000	1Mbps
Data Rate (dB-kbps)	30	
Implementation Loss (dB)	-2	
Available Eb/No (dB)	16.35507	
Bit Error Rate	10^(-5)	
Modulation Scheme	DQPSK	
Required Eb/No (dB)	12	
Coding Gain (dB)	0	no coding
Margin (dB)	4.355072	

Link Budget for AIR TO GROUND Link

FIG. 6

Parameter	Value	Remarks
Transmit Power (dBm)	23	
Carrier Frequency (GHz)	2.442	
Wavelength (meter)	0.12285	
Transmit Antenna Diameter (cm)	20	
Transmit Antenna Efficiency	0.6	60% Efficiency
Transmit Antenna Gain (dBi)	11.95759	
Transmitted EIRP (dBm)	34.95759	FCC allows up to 36 dBm
Range (Miles)	200	
Range (Km)	321.8	
Free Space Loss (dB)	-150.348	
Boltzmann's Constant	-228.6	
Other Link Losses (dB)	-1	
Receive Antenna Element Gain (dBi)	-2	
Receiver Nose Figure (dB)	3	
Receiver Noise Figure (dimensionsless)	1.995262	
Receiver Noise Temperature (K)	288.6261	
Antenna Noise Temperature (K)	70	
System Noise Temperature (K)	358.6261	
System Noise Temperature (dB.K)	25.54642	
Receiver G/T (dB/K)	-27.5464	
Pr/No (dB.bps)	54.66277	
Data Rate (kbps)	4.8	
Data Rate (dB-kbps)	6.812412	
Implementation Loss (dB)	-2	
Available Eb/No (dB)	15.85036	
Bit Error Rate	10^(-5)	
Modulation Scheme	DQPSK	
Required Eb/No (dB)	12	
Coding Gain (dB)	0	no coding
Margin (dB)	3.850361	

Link Budget for GROUND TO AIR Link

FIG. 7

SYNCH	ADD	PRI	DATLNTH	ENC	DATA	EDC

SYNCH - SYNCHRONIZATION PREAMBLE

ADD - ADDRESS(ES)

PRI - PRIORITY

DATLNTH - LENGTH OF DATA FIELD (BITS or perhaps BYTES)

ENC - ONE BIT FLAG DENOTING PRESENCE OR ABSENCE OF ENCRYPTION

DATA - DATA FIELD

EDC - ERROD DETECTION FIELD (computed over the ADD, PRI, DATLNTH, ENC, and DATA fields)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 0292811 A **[0004]**
- FR 2693068 A **[0004]**
- US 5065321 A **[0004]**
- US 5867801 A **[0004]**
- US 5742336 A **[0004]**
- EP 0748082 A **[0004]**